Age and Growth of the Snapper *Chrysophrys auratus* Forster. in the Hauraki Gulf

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Abstract

Two means of estimating the growth rate of the snapper have been investigated: scale reading and length-frequency. It is shown that a curvilinear relationship exists between size of fish and diameter of scale. Owing to the difficulty of determining the exact form of this relationship it has been found expedient to reject the back-calculation method of growth estimation On comparison of determinations of mean age group length by scale reading and length-frequency methods, discrepancies in estimates of mean, standard deviation and number are common. Since the length-frequency solution gives approximately normally distributed age classes, while the scale reading age classes are frequently polymodal, it is considered that the former is likely to be the correct interpretation. In order to obtain a satisfactory range of the smaller sizes of snapper it was necessary to use a trawl of about 1¼ inch mesh Some of the more reliable determinations by the small-fish trawl and length-frequency analysis method are presented Their limitations are discussed and some recommendations are made regarding future investigations

Introduction

In a previous paper (Cassie 1955, Table 28) a table has been given of the estimated mean growth rate of the snapper in the Hauraki Gulf. This has been derived from a series of data collected principally during the years 1949 to 1953. All estimates of the size-age relationship were plotted on a common graph, and a smooth curve was drawn by eye to give what appeared to be the best fit, making due allowance for the varying degrees of reliability of different sets of information. While it is believed that this table is sufficiently accurate for the purposes for which it has been employed (a tentative estimate of optimum mesh size) it is evident that a more critical appraisal must be made both of the methods of age determination and of the results obtained The figures already given will doubtless form a convenient reference until better are obtained, but are of little value in more critical work where the comparison of growth between different regions, seasons, races or year classes is desired. In the present communication therefore the main objects are: to assess the techniques employed, indicating the errors inherent in them; to present those estimates for which the reliability has been reasonably well established; to indicate the lines along which future investigations might profitably proceed

Four methods are commonly used for the determination of age in fish:

1. The "reading" of scales, otoliths and other hard parts
2. The analysis of size-frequency distributions.
3. Marking and recapture
4. Observation of captive fish

Since each of the methods is subject to its own peculiar sources of error, it would be desirable to employ all four, but in the present case it has only been possible to obtain results from the first two A number of snapper have been marked in the Hauraki Gulf and other areas, but no returns have yet been obtained. This may be due in part to the fact that the snapper seems to be particularly susceptible to damage by the trawl, which is otherwise the most convenient method of taking these fish in adequate numbers Even in shallow water and with very short tows there is

a tendency, particularly among the larger fish, for the body cavity to become distended with gas so that the fish has difficulty in diving to the bottom again Even those which are not obviously incapacitated are susceptible to attack by sea birds and (presumably) by predatory fish. No facilities are at present available for stocking and maintaining a suitable aquarium in the Auckland region for the keeping of captive snapper.

Scale Reading

Age determination by this method depends upon the fact that, in many species of fish, annual periodicity in climate or in the behaviour of the fish is reflected by variations in the pattern of growth of various permanent hard parts such as scales, otoliths, fin rays or bones. Both otoliths (sagittae) and scales of the snapper have been examined and found to exhibit a pattern of concentric annuli which in any one fish is usually consistent both between different scales and between scales and otoliths. Since scales are much more readily removed and handled both in the field and in the laboratory, and can if necessary be taken without killing the fish, there is little to be gained in using otoliths which necessitate decapitation of the fish and, if large, require to be sectioned before they can be studied satisfactorily. Plate 28, Figure 1, shows a scale which has six distinct annuli, so that the fish concerned would be assigned an age of 6+ years Each annulus appears under low magnification as a fine transparent line concentric with the margin of the scale Intersecting the annuli from the anterior edge (upper edge in the figure) are nine radii converging to the focus of the scale which represents the original scale platelet of the young fish. Plate 28, Figure 2, shows the detail of the area marked with a white rectangle in Figure 1. Parts of two radii and one annulus are seen, the latter appearing as a distinct interruption in the sculpturing as if growth had ceased for a period and then recommenced. The fine sculptured lines are sometimes known as circuli, though in the snapper they are not completely circular, but lie more or less parallel to the proximal edge of the scale, so that outside the sector delimited by the radii they intersect the annuli and terminate at the edge of the scale It can hardly be claimed that the specimen illustrated is "typical", since it has been selected for the clarity and regular spacing of its annuli As will be seen below, a considerable proportion are not so clearly defined. Obviously even one doubtful annulus makes the scale unsatisfactory for accurate age determination.

In the earlier stages of this investigation scale samples were taken from fish chosen at random from trawl catches Ten or more scales were removed from the side of each fish and placed in a small envelope on which was recorded the length and sex of the fish together with the date and number of the trawl shot Later, in order to minimise variation in the size of scales, it became the practice to take them from one part of the body only, the region immediately behind the head and above the lateral line being chosen for this purpose Still later, when it was found desirable to combine scale reading with length-frequency determinations, scales were taken from entire catches of small-fish trawl shots made especially for this purpose

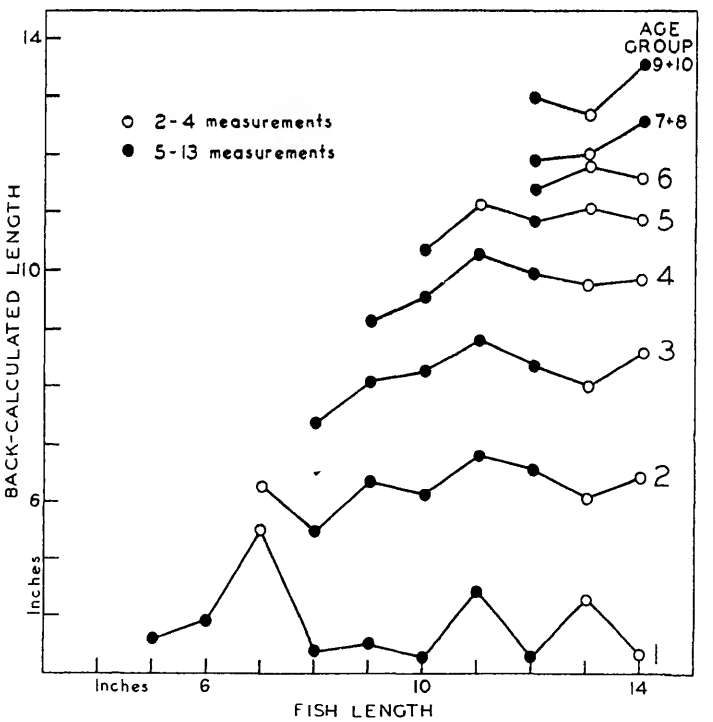
Two principal methods may be employed for the interpretation of scales. In the first the annuli are simply counted and an age assigned to each individual fish Usually this is expressed as 0+, 1+, 2+, etc, under the assumption that the age in years is equal to the number of annuli plus the fraction of a year which has expired since the formation of the last annulus This expression requires a further correction term if the first ring is not formed on or about the first "birthday" of the fish concerned. In the case of the snapper, however, it appears that the ring is formed at the time of spawning which occurs between November and February Scales taken about January usually have an annulus very close to the outer margin, while later in the year the distance from the margin increases, reaching a maximum about November.

The second method, commonly known as "back-calculation", depends on the assumption that, throughout the life of the fish, a constant relationship is maintained between size of fish and size of scale Since an annulus represents a former scale margin, the size of the fish when this annulus was formed may be computed if this relationship is known The simplest case is described by the equation:

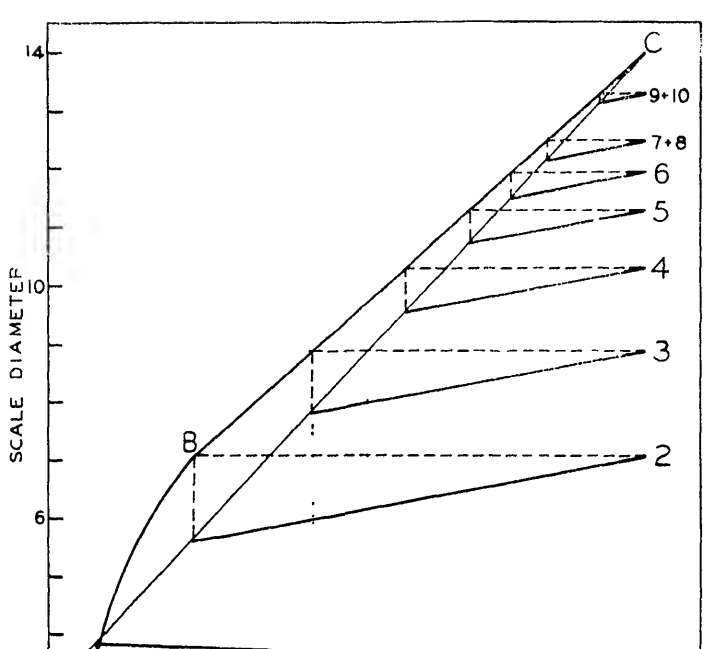
$$l = L\,d\,/\,D \qquad (1)$$

where l is the length of the fish when the annulus was formed, L is the present length, d is the diameter of the annulus, and D is the present diameter of the scale. The measure of fish length employed in the present work was the "fork length" (i e., the distance from the tip of the premaxilla to the centre of the V-shaped notch in the caudal fin), while the diameter of scale or annulus was the maximum diameter (i e, the width from left to right in Plate 28, Figure 1). Various other linear dimensions either of fish or scale would serve as well, but the above are the most conveniently measured Since the three terms L, d and D may be readily determined, it is a simple matter to estimate the entire growth record of any fish by computing l for each successive annulus One of the principal advantages of this method is that the maximum amount of information can be obtained from the minimum number of scale samples

If any appreciable degree of allometry exists between scale and fish dimensions, equation (1) must be suitably modified, the usual process being to compute from a sample of suitable size the regression of fish length on scale diameter. Examination of a small sample of snapper immediately showed that the relationship was unlikely to be a simple proportional one. For a sample of 25 snapper ranging in size from 6



TEXT-FIG 1 —Back-calculated lengths for age groups 1 to 10 plotted against actual length of fish for 80 snapper from Hauraki Gulf.



TEXT-FIG. 2.—Derivation from Text-fig. 1 of an estimate of the regression curve (A-B-C) of scale diameter on fish length

to 29 inches the linear regression equation of mean diameter (measured in arbitrary units) of six scales on length of fish was found to be:

$$\textit{Scale diameter} = 0\ 5204\ \textit{fish length} + 0{\cdot}7480 \qquad (2)$$

With a standard error of 0 1160 the intercept, 0 7480, differs from zero at the 0 1 per cent. level of confidence, so the simple proportional relationship obviously does not hold. As a test of linearity the allometric regression equation was computed:

$$\textit{Scale diameter} = 0\ 7382\ \textit{fish length}^{\,0\ 9062} \qquad (3)$$

The exponent, 0 9062, with a standard error of 0 0298, differs from unity at the 1 per cent. level of confidence. Thus it is unlikely that there is a linear relationship between fish length and scale diameter. The exact relationship is less easily determined since, even with the most careful standardisation of the position from which they were taken, scale sizes for any one fish were extremely variable, with a coefficient of variation up to 20 per cent in some cases.

However, it is not the absolute size of annuli which is significant, but their size relative to that of the scale Thus it has been possible to reconstruct the approximate shape of the regression curve by a method which is independent of variations in scale diameter Text-fig 1 presents the results of scale readings from a sample of 80 snapper ranging in age from one to ten years Lengths back-calculated for each age group by equation 1 are plotted against length of fish from which the scale was taken. Apart from the first age group, there is a distinct tendency for back-calculated lengths to increase with the actual length of the fish. In Text-fig. 2 a series of regression lines have been fitted by eye to the points for each age class The line O-C, representing equation 1, intersects these regression lines at points which, when projected onto the abscissa, give an estimate of the mean fish length when each succes-

sive annulus was formed—i.e., the growth rate. (For instance, a fish forming its third annulus will be expected to be about 7 8 inches long.) The ordinate of the graph may now be used as a measure of "scale diameter"; not the diameter of any actual scale, but that of an hypothetical "average" scale with a size variation dependant only upon length of fish. Since only an arbitrary measure is required, the same units may be employed as before, so that the basic unit is 1/14 of the scale diameter of a 14-inch fish. Co-ordinates (broken lines) are now drawn from either end of each regression line to intersect at a series of points which are joined by the curve A-B-C. This is an estimate of the regression of scale diameter on fish length in the range 4–14 inches. Since it was desired to obtain only an approximate picture of the shape of the curve, the diagram has been simplified by making the age group regression lines parallel (with the exception of 1). Thus B-C becomes a straight line with a positive intercept (cf. equation 2) although it is not unlikely that the entire curve A-B-C is curvilinear (cf equation 3) It is clear then that the simple back-calculation relationship given in equation 1 will give a biased estimate of the growth rate. For instance (following the dotted co-ordinates in Text-fig. 2) the third annulus of a 14-inch fish will have a diameter of 8·9 units, corresponding to a back-calculated length of 8·9 inches, as compared with the true value, 7 8 inches. Since, in these investigations, there was virtually no limit to the number of scale samples which could be obtained, the back-calculation method was abandoned in favour of the simpler method by which each fish yields only its length and age at time of capture.

Three different techniques were employed in the reading of scales. In the first stages of the investigation they were simply placed dry under a low-power stereoscopic microscope Later a reading apparatus was constructed in which the scale was placed in a small projector which was directed vertically downward onto a mirror, so inclined that the image was projected onto an inclined ground-glass screen immediately in front of the projection stage. The whole apparatus was enclosed in a plywood case and recessed into a bench so that the screen was at a convenient working level. By this means the magnified image could be viewed with a minimum of eye strain in ordinary room lighting and, if necessary, measurements could be taken with a celluloid rule. The scale was usually examined dry, being held flat between two glass plates, but provision was made for water or glycerine mounts in the few cases where these were considered necessary. Usually little preparation was needed beyond washing in tap-water and rubbing off any foreign matter between thumb and forefinger. In the third method the scale was placed on a matt black surface and viewed with the unaided eye by oblique incident illumination. By this means some determinations could be made very easily and rapidly, but in cases of uncertainty the projector was always employed

In every case at least five scales were examined, regenerated scales (which do not have a complete growth record) being rejected. If the first five gave inconclusive results a second five were examined, but it was found that little could be gained by increasing the number above ten. Results were recorded on a cyclo-styled sheet with appropriate spaces for: serial number, length of fish (inches and tenths), sex, number of annuli, alternative annulus count (if any), reliability of reading, number of scales examined, and remarks In the reliability column was entered a code letter ranging from "A" where the reading was clear and consistent in all scales, to "D" where no interpretation was possible. Though this classification is largely subjective, it was of considerable value in comparing the interpretations of different observers. It was found, for instance, that if both placed a set of scales in category "A" there was seldom if ever any disagreement over the number of annuli counted. Determinations not classed as "A" were checked by a second observer, while in summarizing results "C" and "D" categories were rejected as unreadable. As a check on personal errors 100 sets of scales of snapper ranging from 3 to 6 inches in length were read independently by three different persons. It was found that in only 53

sets were all three determinations in agreement, and that in every case these had been placed in category "A" or "B" by all. After the three had conferred over the results, unanimity was reached in a further 14 cases, while two out of three agreed in 11 cases. For the remaining 22 no definite decision could be reached. The majority of the fish in the sample were in the 1+ and a few in the 0+ and 2+ age classes, so that they represent almost the simplest possible case for age determination. The difficulty of obtaining consistent estimates increased with the size and age of the fish concerned, until at about eight years no accurate estimate at all was possible. Larger fish showed apparent ages of 20 years or more, but the closely crowded annuli near the periphery of the scale defied any precise count.

Length-frequency

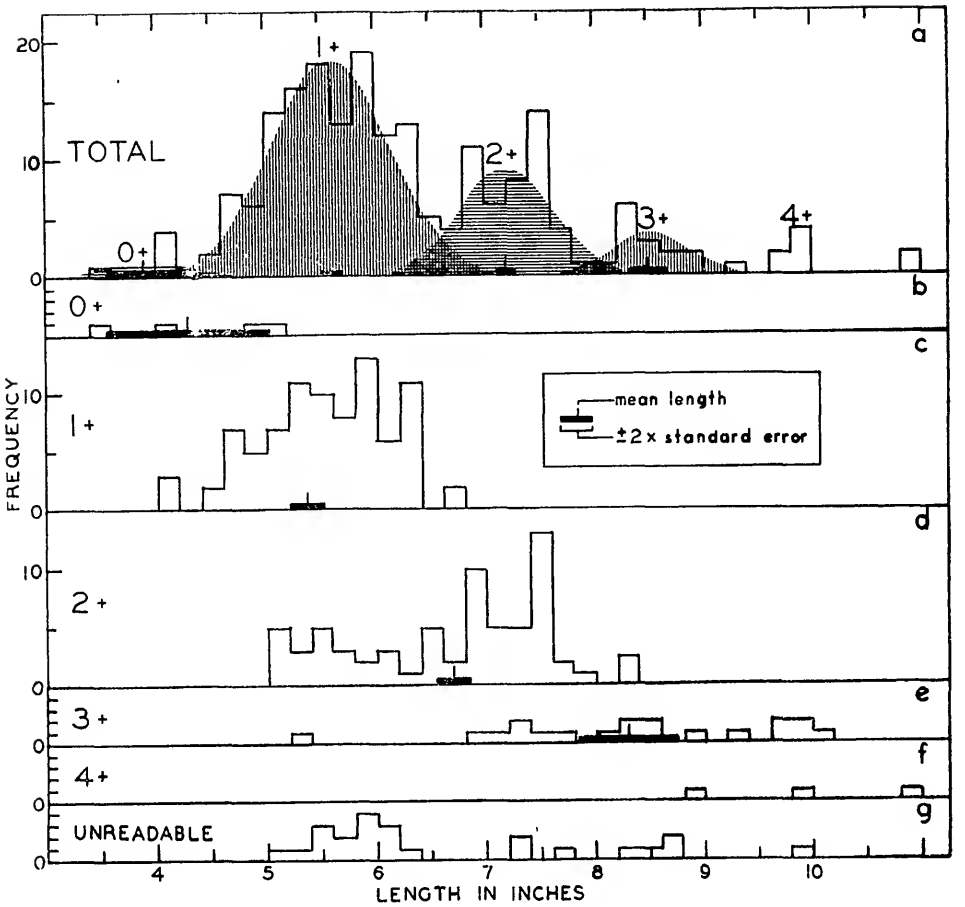
This method depends upon the fact that many species of fish have a relatively constant and limited spawning season each year, so that the population consists of a series of age groups each with its own size range distinct from that of adjacent classes. When the frequency distribution of length (or any other suitable measurement character) is plotted, these age groups are indicated by modes in the distribution. The method is usually limited to the younger fish, since the modes tend to crowd together and eventually become indistinguishable as the growth rate decreases in later life. Since the snapper does not figure largely in the catch of the commercial trawl until it is three or four years of age (Cassie 1955, pp. 66, 67), the usual samples taken by the research vessel "Ikatere" were of little value, and a "small-fish trawl" (actually a prawn trawl purchased in New South Wales) with 7 fathoms head and footrope and approximately $1\frac{1}{4}$ inches mesh throughout was employed. This trawl did not fish particularly well and was not sufficiently strong for heavy use, but unfortunately no more suitable substitute was obtainable while the author was engaged in this investigation. Nevertheless, sufficient data have been collected to show the potentialities of this method.

In a previous paper (Cassie 1954, pp. 514-517) the method of dissecting length-frequency distributions into the components represented by the modes has been described. In the majority of samples it was found that each "age group" approximated sufficiently closely to a normal distribution to give a good fit as judged by the χ^2 test.

Comparison of Scale Reading and Length-frequency Results

A method has also been described (Cassie 1954, p 517) by which the results of scale readings may be co-ordinated with those from length-frequencies. In the example given, significant discrepancies were found between the results given by the two methods for certain age groups, suggesting that one or other method was invalid. In only six small-fish trawl catches were the numbers of snapper sufficient for adequate analysis, but not one of these shows complete consistency between scale reading and length-frequency determinations of age. The difficulty in interpretation is further increased by the high proportion of unreadable scales, but for the purposes of illustration it has been possible to choose a set of results (Text-fig. 3) where 90 per cent. of the scales have been interpreted. Similar results were obtained from each of the other five samples.

Text-fig. 3a shows the length frequency of the catch (totalling 201 fish) plotted in histogram form Superimposed on this the hatched areas depict the hypothetical normally distributed population curves as estimated by the probability paper analysis Although the histogram appears somewhat irregular compared with the smooth curve, it must be remembered that the number of fish in each class is small, leaving a considerable margin for chance variation A test of goodness of fit gives $\chi^2 = 12\ 158$



TEXT-FIG 3.—Analysis of age groups of a sample of 201 snapper by length-frequency (a) and scale-reading (b-g).

with 14* degrees of freedom, the probability of a higher value of χ^2 occurring by chance being approximately 0 5, so that there is no reason on this score to doubt the validity of the analysis The estimated age-class parameters are shown in Table 1

TABLE I.

Estimated Age-group Parameters (Length-frequencies).

Age Group	n	$\bar{x}$	s
0+	6	3 9	0 42
1+	124	5 6	0 54
2+	48	7 2	0.42
3+	15	8 5	0.33
4+ and over	8	—	—
	201		

Where n = number of fish
$\bar{x}$ = mean length in inches
s = standard deviation of length.

* After grouping to avoid expected numbers less than 5 in any size class, 27 size classes remain From this figure must be subtracted one degree of freedom for each of the 13 parameters shown in Table 1, leaving 14 degrees of freedom

The corresponding parameters as determined by scale-reading (Text-fig. 3, b-g) are given in Table II.

TABLE II.

Estimated Age-group Parameters (Scale-reading)

Age Group.	n	x	s
0+	4	4.3	0.76
1+	85	5.4**	0.55
2+	70	6.7***	0.57*
3+	19	8.3	0.95**
4+	3	—	—
	181	—	—
Unreadable	20	—	—
	201	—	—

t test of significance of differences from Table I

* significant at 5% level.

** significant at 1% level.

*** significant at 0 1% level.

Comparing the two tables, it is clear that in each of the three larger age groups one or more parameters differ significantly. Thus in classes 1+ and 2+, n differs by a number greater than can be accounted for by unreadable scales, while the difference in x is highly significant. In 3+, n and x do not differ greatly, but the difference in s is highly significant. There is no clear indication in Tables I and II which is more likely to be the correct version, but referring once again to Text-fig. 3, it will be noted that the length-frequency distribution of the scale-reading age groups is in some cases quite clearly divergent from normal For instance, the 2+ class has at least two modes which appear to correspond to the 1+ and 2+ classes in the length-frequency analysis, while the isolated block on the right might well belong to the 3+ class. A similar interpretation might be placed on nearly all the scale-reading age classes. It will be noted that the unreadable section (Text-fig. 3, g) has a very similar distribution to the parent sample, except that (as might be expected) there is a tendency for more unreadable scales to be found in the larger sizes. The discrepancy between the results of the two methods is also made apparent in the figure by the dark horizontal bars along the bases of the histograms, representing the interval *mean* $\pm$ 2 $\times$ *standard error* for each apparent age-class.

From the above considerations it is concluded that the length-frequency solution is the more acceptable of the two. Although it is by no means axiomatic that measurement characters in any homogeneous group such as an age group should be normally distributed, when a normal distribution can be fitted to a series of apparent age-groups, such a solution is more convincing than an erratic series of polymodal classes The latter can quite reasonably be explained on the assumption that, although there is a tendency for one annulus to be formed every year, annuli may sometimes be omitted or duplicated, owing perhaps to variations in seasons or in the behaviour of the fish. Some weight is lent to this supposition by the fact that snapper scales taken from the west coast of the North Island and Tasman Bay have more regularly spaced annuli and are more easily read. The scale shown in Plate 28, Fig. 1, for example, was taken in Tasman Bay and, for its size, is much more legible than any taken in Hauraki Gulf. Compared with the Hauraki Gulf, the west coast is a relatively exposed region with few sheltered bays and harbours. Thus the Hauraki Gulf snapper may, by relatively short-range wanderings, experience in any one year a number of different hydrographic conditions which may induce or suppress annuli. The west coast snapper on the other hand must either be subjected to regular annual changes in its aquatic environment or make annual migrations, either of which would tend to produce an annual pattern of scale growth It is perhaps significant that both in Tasman Bay and Manukau Harbour, seasonal migrations distinguished by changes in the size composition of the catch are well-known to the fishermen, while in the Hauraki Gulf such movements are less obvious. Thus, even if scale-

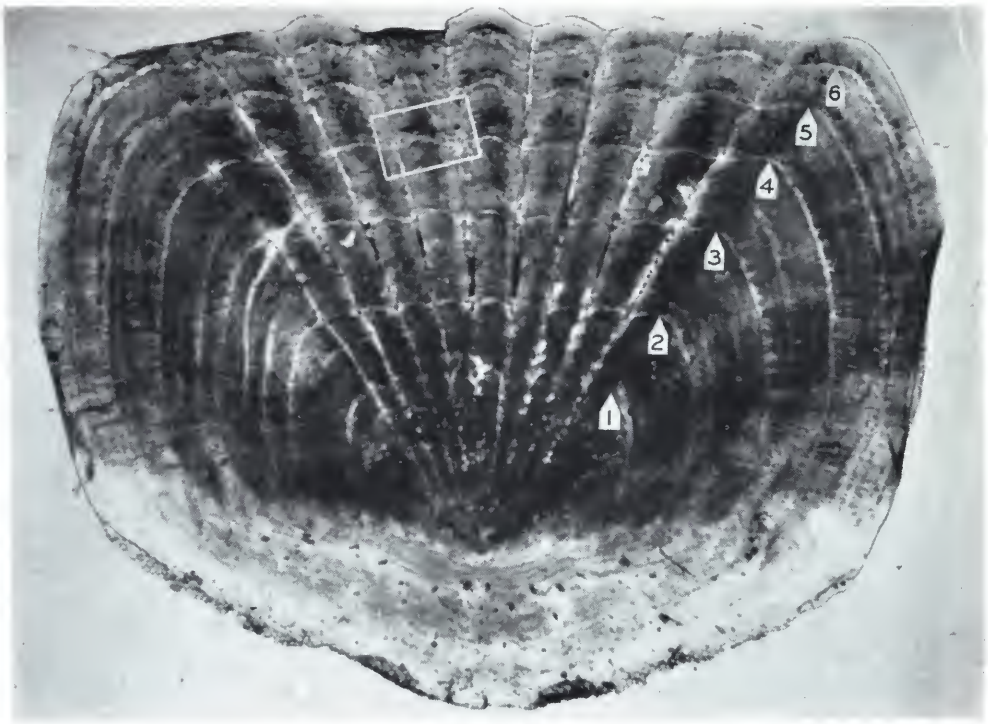


FIG. 1.—Scale taken from a 14-inch snapper, Tasman Bay, showing 6 annuli. × 85.

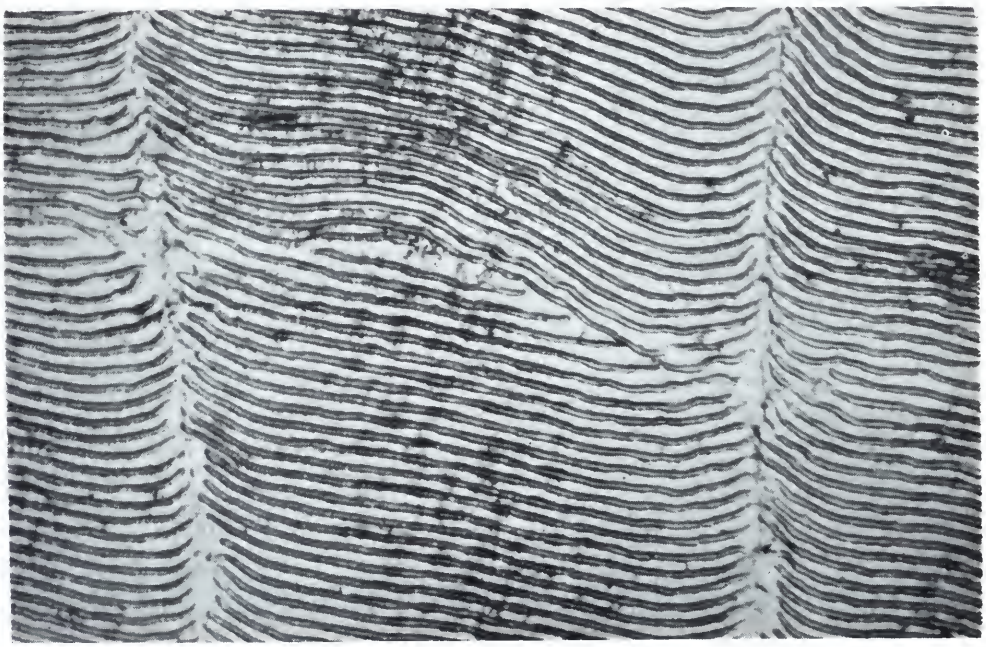
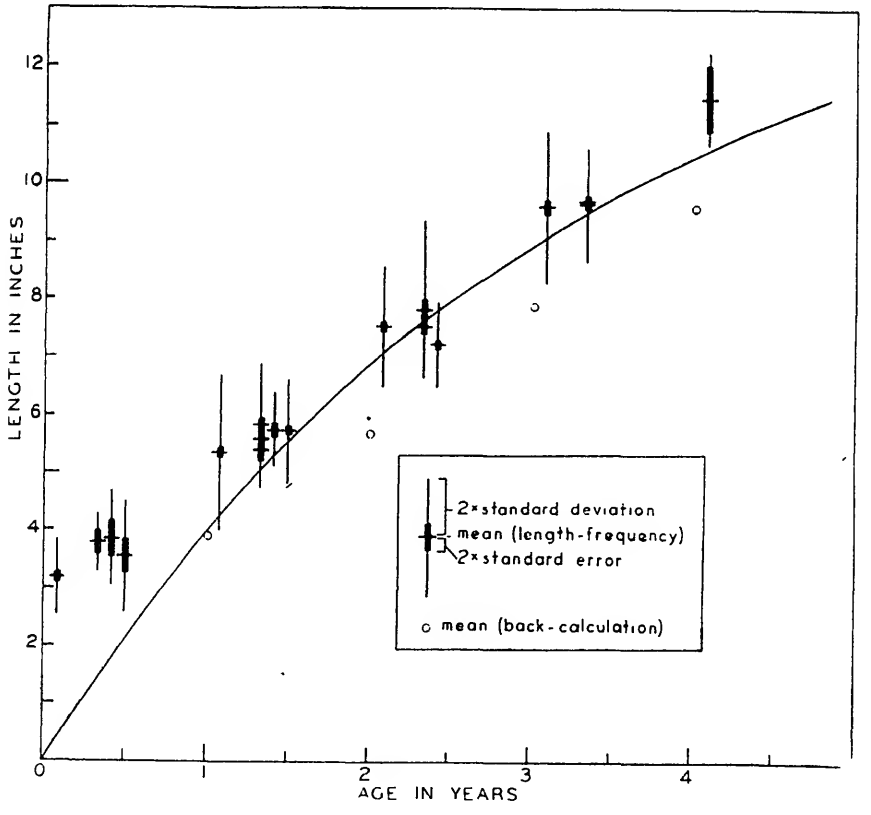


FIG. 2.—Detail of rectangular area marked in Figure 1, showing two radii and one annulus. × 85.

readings are rejected as unreliable for Hauraki Gulf snapper, it is possible that this technique may still produce valid results for other localities

While the length-frequency method appears, on the basis of the above evidence, to be a more satisfactory method of age determination, it is still necessary to examine the possibility that modes might be manifestations not of age groups but of some other form of discontinuous grouping in the population sampled. It is known, for instance, that some species of fish tend to congregate in schools of individuals all approximately the same size A trawl passing through a series of such schools would produce a polymodal sample, each mode representing a school which is not necessarily homogeneous for age. This possibility cannot be altogether discounted until more comprehensive data have been collected, but, as will be shown in the next section, all the length-frequency data so far collected yield results consistent with the age group hypothesis Such agreement would scarcely be expected unless age is at least a major component in determining the position of modes

Although scale reading has been rejected for present purposes, the structure of snapper scales may still repay further investigation, since the same irregularities which render them unreliable for age-determination may be of value for other purposes. If annuli are formed as a response to variations in hydrographic conditions, it is not unlikely that scale pattern may serve in some instances as an index of geographical races For instance, there would be little difficulty in distinguishing, on the basis of scales alone, between two samples of large snapper, one from Hauraki Gulf and one from Tasman Bay.



TEXT-FIG 4—Summary of length-age determinations by length-frequency (Text-fig 3, a) and corrected back-calculation (Text-fig 2) Continuous curve = growth rate from Cassie (1955)

Growth Rate

The results of length-frequency analysis of six small-fish trawl catches are summarised in Text-fig. 4. The zero point of growth has been placed arbitrarily in the month of December, which is about the middle of the usual spawning season in the Hauraki Gulf (Cassie, in press). Thus, in a sample taken, say, in April, the 0+ group would be classed as five months old, the 1+ as 17 months, etc The estimated mean length is represented in each case by a short horizontal line, while the light and heavy vertical bars indicate the ranges: *mean* $\pm$ 2 $\times$ *standard deviation,* and *mean* $\pm$ 2 $\times$ *standard error* respectively The curve superimposed on these points is the growth curve presented previously (Cassie 1955, Table 28). It will be noted that the points determined within each age group do not lie along this curve, but tend to have a somewhat flatter regression of their own, producing a series of steps in the overall curve. This is, however, to be expected, since more growth is likely to take place in the warmer summer months, and a smooth growth curve would be to some extent artificial, since it takes no account of seasonal variation If allowance is made for this factor, the points shown agree reasonably well with the general trend of the curve, except in the case of the 0+ year class. This one exception is almost certainly due to the fact that the mesh of the trawl is not sufficiently fine to capture the smaller fish. Taking the mesh size as $1\frac{1}{4}$ inches, it may be computed from the equations for escapement and selection (Cassie 1955, p. 72) that 50 per cent. of all 3-inch snapper and 90 per cent of all 2-inch snapper will escape from the trawl Thus only the largest of the 0+ year class will be taken, and the sample mean length will over-estimate the true population mean In this connection it is interesting to note that Roughley (1916) states that in New South Wales waters "cockneys", which are snapper in their first year, range between 3 and 4 inches long. Obviously very much smaller fish than this must occur in the first year of life, but it is not until a length of about 3 inches is reached that yearlings are likely to appear in any normal type of fishing net

The estimated length at each year, from the scale reading analysis in Text-fig. 2 has also been incorporated in Text-fig. 4 (circles). Although it is not to be expected that these lengths will be very reliable, they are not entirely incompatible with the general shape of the curve determined by length-frequency determinations

Conclusions

The combination of small-fish trawl with length-frequency analysis appears to be the most satisfactory technique so far devised for estimating growth rate in the snapper Text-fig. 4 summarises the more reliable of the estimates which have been obtained in this way. It may be desirable in the future to extend these observations by collecting a more continuous series, preferably with somewhat larger samples (about 500 fish per catch would probably be ideal) and extending over a period of one or more years Since no one mesh size takes a fully representative sample, the use of several grades of trawl would be advantageous. The unreliability of the scale-reading method also makes it desirable to obtain an independant check on results by other means such as marking and recapture It is, however, quite possible that the reading of scales may be much more profitable for snapper investigations in other regions such as the west coast of the North Island or Tasman Bay

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